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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : B03C 7/02, 7/12

A1

(11) International Publication Number: WO 93/06934

(43) International Publication Date: 15 April 1993 (15.04.93)

(21) International Application Number: PCT/US92/00184

(22) International Filing Date: 10 January 1992 (10.01.92)

(30) Priority data:
769,088 30 September 1991 (30.09.91) US

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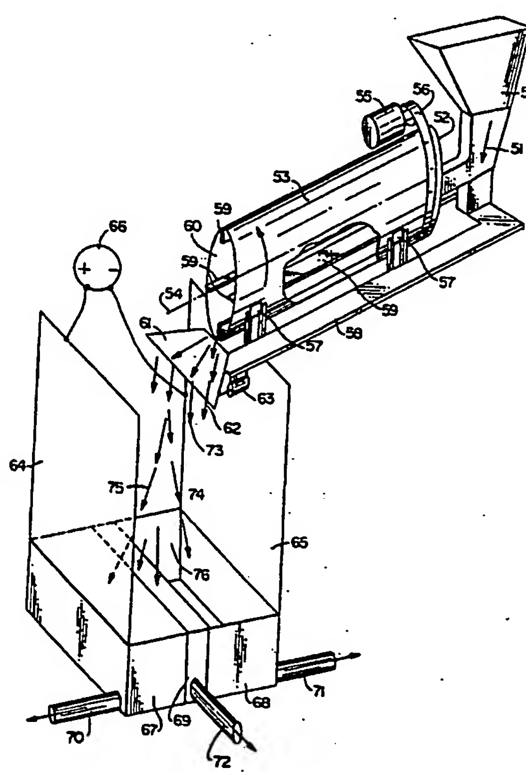
(81) Designated States: AT, AU, BB, BG, BR, CA, CH, CS, DE, DK, ES, FI, GB, HU, JP, KP, KR, LK, LU, MG, MN, MW, NL, NO, PL, RO, RU, SD, SE, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IT, LU, MC, NL, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, SN, TD, TG).

Published
With international search report.

(54) Title: ELECTROSTATIC SEPARATION OF PLASTIC MATERIALS

(57) Abstract

An apparatus and associated method of separating mixed fragments of different plastic materials (2), in which the material (2) to be separated are capable of carrying different electrostatic charges. The charges are induced in the mixed fragments by a precharging hopper (3, 32) or by tumbling in drum (53). The charged fragments are then exposed to at least one electrostatic field in which they are separated by migration under the influence of the field. The field can be along an inclined sheet (4) or a free fall path. The separated material fragments are then collected.



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ELECTROSTATIC SEPARATION OF PLASTIC MATERIALS

This invention relates to the electrostatic separation of plastic materials.

Background

Disposal of solid waste has been a growing problem and has risen to crisis levels in some parts of the country. One solution to the problem is to recycle materials that normally are landfilled. Various materials can be pulled from the waste stream and recycled with one such component being the different plastic materials.

Further, there are other industries that wish to reclaim materials. Industries such as wire & cable and automotive have a multitude of materials that have value and could be reclaimed. A major obstacle to the reclamation of commingled plastic materials is the extreme difficulty to separate them into discrete components.

It is important to note that reusing commingled plastics (ie, without separation) is not cost effective nor efficient and further substantially reduces the properties of the plastic materials. For example, PET and PVC materials are not compatible. PET melts at about 500°F while PVC will degrade at approximately 400°F. Upon degrading, PVC gives off hydrochloric acid which destroys the desirable properties of PET material. It should be noted that small amounts (on the order of 1 part in 500) of PVC mixed in with PET will destroy PET when the two materials are melted together.

Each of the noted industries, as well as other applications utilizing plastic materials, uses many

different types of plastic materials. As an example but recognizing other industries or markets pertain also, the plastic packaging industry will be focused upon.

Typical rigid household plastic packages (bottles and other type containers) are made of 5 plastic materials. Other plastic materials are used as well, but the 5 highest volume materials are:

- PE (Polyethylene; High Density (HDPE) Low Density (LDPE))
- PET (PolyEthylene Terephthalate)
- PVC (PolyVinyl Chloride)
- PP (PolyPropylene)
- PS (Polystyrene).

To collect the various plastic materials in an economic manner, all the different material bottles are thrown together and commingled. The bottles are either compacted (baled) or ground (chopped into smaller particles) for space reduction. The most efficient manner would be to grind the whole bottle at the point of collection. Because of the difficulties described in separating the ground particles, this method has not been widely introduced.

Some of the applications for the plastic containers are clear while some are colored (transparent -> opaque). An existing method to separate the different materials is to sort by hand. This method is costly and fraught with error as many applications utilize two or more plastic materials. For example, edible oil bottles are made from both PET and PVC materials. This method can only be used with whole bottles and preferably when they are not crushed.

Another method being investigated to separate whole PVC bottles from other plastics is one which uses an energy source to excite the chlorine molecules which are

then detected. The bottle is thus identified and ejected from the stream. This method is still experimental but it also has drawbacks in that whole bottles are required, it utilizes radiation sources such as x-rays which pose safety and health hazards and further make the system expensive to operate and maintain.

For ground commingled materials, a more effective manner of separating some of the plastic materials is to separate via the differences in density of the various plastic materials. Generally, this is effective only in separating the materials with densities with < 1 g/cc. Materials with densities < 1 g/cc generally are PE and PP.

The separation process generally is a float/sink operation where the lighter fractions float on water and are culled off while the heavier fraction sinks to the bottom. The heavy fraction would generally constitute PET, PVC and PS. The densities of these materials are very similar and in the case of PET and PVC they overlap. As an example; typical PVC densities range from 1.25 to 1.36 g/cc while typical PET ranges from 1.32 to 1.39 g/cc. With the overlap in densities, separation via the float/sink method (even using solvents with densities > 1 g/cc) will not work.

Object

It is an object of the present invention to provide a more efficient, economical and effective method and apparatus for separating plastic materials particularly, though not exclusively, to obtain previously used PET sufficiently free from other plastics to facilitate recycling thereof.

Summary

It has been discovered that when two ground commingled plastic materials (e.g. PVC and PET) are subjected to electrostatic precharging on the surface of the plastic particles, the PVC becomes negatively charged and the PET becomes positively charged. The charged particles can then be attracted toward oppositely charged poles. Further, the particles will not be attracted to each other unless the static surface charge on the particle becomes too great.

According to the invention there is provided a method of separating mixed fragments of different materials, at least one said material being capable of carrying an electrostatic charge by which it can be caused to migrate under the influence of an electrostatic field sufficiently to separate it from at least one other said material, comprising the steps of inducing said electrostatic charge on said at least one said material, exposing the materials to an electrostatic field capable of causing migration of said at least one material relative to at least said one other said material, allowing said at least one material to migrate under the influence of said field thereby to separate said materials, and collecting the separated material fragments, wherein the induced electrostatic charge on said at least one material is sufficient to facilitate said migration while being insufficient for any oppositely charged fragments of said materials to be attracted to each other sufficiently to prevent said migration.

According to another aspect there is provided an apparatus for carrying out the above defined method comprising means for inducing said electrostatic charge on the fragments of said at least one material, means for producing an electrostatic field capable of causing

migration of said charged fragments relative to at least one other said material, means for exposing said mixed fragments to said field, and means for collecting the separated material fragments.

Brief Description of the Drawings

The invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a diagrammatic side elevation of a first experimental electrostatic plastic material separator;

Figure 2 is a diagrammatic plan of the separator of Figure 1;

Figure 3 is a diagrammatic side elevation of a second experimental electrostatic plastic material separator;

Figure 4 is a diagrammatic representation of a proposed commercial embodiment of an electrostatic plastic material separator;

Figures 5 to 9 diagrammatically illustrate various examples of possible electrode configurations; and

Figures 10 and 11 illustrate charge distributions of PVC and PET fragments.

Turning to Figures 1 and 2, a first embodiment is detailed illustrating an electrostatic separator 1 for separation of ground PVC and PET, or other commingled plastic particles 2, each 5/8 inch or less in size. The separator comprises an electrostatic precharging hopper 3, which is mounted at or near the top of an inclined sheet 4, wherein the hopper and the inclined sheet 4 are made up of insulating materials, preferably one of the plastic materials to be separated (in this embodiment; PET) to assist in the transfer of electrons.

Two strips of conductive material 6, 8, typically aluminum foil, are attached to the underside of the

inclined sheet 4, positioned so that one strip 6 continuously traverses the two sides and the bottom edge of the sheet 4 while the second strip 8 is centrally located from the top edge of the sheet 4 extending therefrom toward the first strip bottom edge. The strips 6, 8 are separated from one another by an insulating gap and are attached to an electric generator 12 by means of leads 10, the second strip 8 being attached to the negative terminal and the first strip 6 being attached to the positive terminal of the generator 12, thereby producing oppositely charged electrostatic poles defined by the strips 6 and 8. Other configurations involving conductive strips are possible provided that separate, appropriately charged electrostatic fields are created.

The hopper 3 has a gate means 5 which can be opened to release the commingled particles allowing them to migrate down the inclined sheet 4. A vibration device 14 enhances this migration by causing the commingled particles to bounce into the air as they proceed down the chute formed by the incline.

Further, the sheet 4 has three collection holes 18 located on its lower half to collect separated particles wherein each hole 18 has a corresponding collection cup 20 placed underneath it to collect particles which drop through. Finally, path diverters 21 are attached to the top of the inclined sheet 4 to assist in the separation and collection process. Diverters are not shown in Figure 1.

In use, the commingled PVC and PET particles 2 are placed in the precharge hopper 3 where they receive an induced electrostatic charge causing the surface of the PET particles to become positively charged and the surface of the PVC particles to become negatively charged. The

precharge hopper 3 is made from insulating material, preferably of a plastic material to be separated (PET in this embodiment), to facilitate the transfer of electrons. The induced charge must be applied for a sufficient duration and at a sufficient strength to create opposite charges on the surfaces of the plastic particles but should not be great enough to cause the particles to attract one another, preventing separation. It has been found that a charge of between 3000 and 10,000 volts for a period of 30 seconds to 60 seconds produces adequate results.

The mixed particles 2 upon acquisition of the induced charge are released from the hopper 3 by opening the gate 5 allowing the particles to migrate down the inclined sheet 4 facilitated by the vibrating member 4 whose oscillations causes the particles to bounce into the air.

The conductive strips of aluminum foil 6, 8 placed on the underside of the inclined sheet act as positive and negative poles respectively, produce electrostatic fields of opposite polarity.

The mixed particles, having acquired an induced charge, are attracted to oppositely charged poles, meaning that the positively charged PVC particles are drawn toward the negative pole 8, while the negatively charged PET particles are drawn toward positive pole 6. This electrostatic attraction of unlike charged particles causes the central stream 15 of mixed PCT/PET particles to separate into divergent streams of pure PVC 17 and pure PET 16, respectively, while the remaining central stream 15 contains those mingled particles which either did not develop a sufficient induced charge while in the hopper 3, or developed too great a charge causing interparticular attraction. It has been found that separation is enhanced

by using a thicker inclined sheet rather than a thinner, less insulating, sheet.

The particles are then collected by means of holes 18 with collector cups 20 placed underneath the holes to capture the separated PVC and PET particle streams 16, 17 as well as the mingled particle stream 15. These mingled particles may be recycled through another pass of the separator or set aside.

Diverters 21 placed along the top surface of the sheet 4 facilitate the migration of the separated particles 2 toward their respectively oppositely charged fields as well as assist in collection of those materials by trapping the separated material streams 15, 16, 17 at or near their respective collection hole 18.

Figure 3 discloses a second embodiment of an electrostatic separator 30 in which a precharge hopper 32 is suspended a vertical distance above and between two oppositely charged plates 34, 36, wherein the negative terminal of a generator 38 is attached to one plate 34 and the positive terminal of the generator 38 is attached to the other plate 36 as well as to the precharge hopper 32 by means of leads 40. The vertical plates 34, 36 are composed of a conductive material, such as aluminum foil and are vertically supported by mount stands 35. The plates, therefore, define two oppositely charged electrostatic fields beneath suspended precharge hopper 32.

In use, mixed PVC/PET, or other ground and commingled plastic particles, each typically having a size of 5/8 inch or less are placed in the precharge hopper 32 and are electrostatic charged the precharge hopper 32 being composed of an insulating material, preferably of a plastic material to be separated (PET, in this embodiment)

which allows free migration of electrons allowing the PVC particles to become positively charged and the PET particles to become negatively charged.

The mixed PET/PVC particles upon receiving the induced electrostatic charge are allowed to free fall under the influence of gravity by opening of a gate 33 of the precharge hopper 32. As the stream of mixed particles 41 fall between the oppositely charged poles 34, 36 the negatively charged PVC particles are drawn toward the positive pole 34 and the positively charged PET particles are drawn toward the negatively charged pole 36 producing two divergent streams 42, 43 of pure PVC and pure PET respectively. It has been found that plates possessing equal and opposite charges of ±60KV producing a total potential of 120KV will create horizontal displacement of greater than 1/2cm for each 1cm of vertical drop. The separated streams 42, 43 of form individual 44, 45 of charged PVC and PET particles which can then be collected. The separator of Figures 1 and 2 was designed and run though, some modifications were made as results became apparent. Generally, 25 grams of PET and 25 grams of PVC were used in the trial. Three collections were made from each run; PET - PVC - MINGLINGS.

Each collection was weighed and then separated by hand into components (contamination of each stream, ie, how much PVC in the PET collection). There was a general loss of both PET and PVC from particles falling off the sheet, getting stuck to adhesives used to located diverter plates, etc. These losses were discounted from the outcome as having no bearing on results because the loss was due to the crude structure not the underlying principle.

Various PVC bottles (clear, brown and yellow) were used in the trial. Different PET materials were used also (clear, green and amber). No discernable differences were recorded using the different resins.

General atmospheric conditions were noted such as hot and humid, clear and cool, etc.

RESULTS

The order of best to worst results for PET:PVC separation with the temperature variable is:

- Dried
- Hot
- Room temperature
- Refrigerated

This makes apparent sense as moisture will block the electrostatic field. The refrigerated material has condensation that apparently forms on the surface giving problems while the room temperature material has absorbed moisture that causes some interference.

However, except for the refrigerated material, separation rates of 95-100% occurred for all the temperature variables.

During the trials an important observation was made. As the trial proceeded, it was noted that the separation became 100% and that most of the contamination (% of PVC in PET and vice versa) occurred at the start of the trial. Precharging the material in the holding hopper significantly helped to achieve better separation. However, another phenomenon was observed. If too much charge was given to the particles then the PET and PVC particles would stick together and separation would not occur.

A "middle of the road" charge is required on the materials so they will have enough energy to jump to their

respective (opposite charged) poles but not so much energy they are attracted to each other.

The generating device that was used is called a wimshurst generator. It is a handcranked device that allows a small electrostatic charge to be generated. The leads were connected to the aluminum foil as noted in the sketch. In this manner we were able to create continuous and "wide" (as opposed to a point) poles. Handcranking the generator gave between 3,000 and 10,000 volts as measured with a handheld meter.

Two different particle sizes were tried. The first was plastic that was put through a grinding device that had a 1/4 inch screen. The second size particles were those put through a 5/8 inch screen.

The smaller sized particles separated easier than the larger size, however, the larger size did also separate although at a lower point on the inclined sheet. It was theorized that this is because a large enough charge could not be placed on the larger particles with the handheld device. A commercial unit would probably generate 50,000 to 100,000 volts, thus, giving sufficient charges to be attracted quickly to its opposite pole.

Another experiment on the separation technique as well as additional calculations have been completed. The protocol and results are as noted below.

A 2 liter soft drink bottle (PET) and a Windex bottle (PVC) were purchased. The bottles were cut into small pieces of which 20 particles of each material were placed into a glass jar. The jar was capped and shaken for 15+ seconds to induce a static charge on the surface of each particle.

Each particle was then removed and measured for the total charge

RESULTS

PIECE #	PVC CHARGE	PET CHARGE
1	-.69	+.10
2	-.60	+.41
3	Not available	+.10
4	-.30	+.06
5	-.18	+.37
6	-.55	-.08
7	-.72	+.15
8	-.50	+.21
9	-.55	+.75
10	-.68	+.34
11	-.27	+.23
12	-.61	+.66
13	-.59	+.37
14	-.43	+.49
15	-.32	-.45
16	-.32	+.50
17	-.68	+.12
18	-.63	+.34
19	-.11	-.02
20	-.44	+.26

Calculations

PVC: total charge $Q = -9.56 \times 10^{-9}$ C, total mass M = .8071 grams

$$Q/M = \frac{-9.56 \times 10^{-9}}{.8071 \times 10^{-3}} = -1.185 \times 10^{-5} \text{ C/Kg}$$

PET: total charge $Q = +5.36 \times 10^{-9}$ C, total mass M = .4609 grams

$$Q/M = \frac{+5.36 \times 10^{-9}}{.4609 \times 10^{-3}} = +1.163 \times 10^{-5} \text{ C/Kg}$$

C = Coulombs; Kg = Kilograms

An analysis of a physical free fall (see Fig. 3) with gravity forces and electrostatic charge (force) divided by the mass was conducted. Assumed were two vertical plates (poles) one plate having +60 Kv and the other -60Kv thus the total potential = 120Kv or 10 Kv/inch.

The results show that for every 1 cm vertical drop more than 1/2 cm horizontal movement can take place.

The commingled material, upon exposure to oppositely charged electrostatic fields, is divided into 3 streams:

a) Positive pole attraction;
b) Negative pole attraction; and
c) "Minglings".

It has also been noted that different modes of the same material act differently. For example, PET can exist in three separate states;

- amorphous
- biaxially oriented
- crystallized.

Tests have shown that biaxially oriented material, though having significant separation, has less separation than amorphous or highly crystallized materials. However, by adding amorphous or highly crystallized particles to the biaxially oriented PET and PVC mix, the level of separation increases. The level of separation begins to approach 100% which is the general level achieved by amorphous or highly crystallized particles when mixed with PVC particles.

The PET and PVC separation tests have produced excellent results. 100% purification has been achieved on some tests with one pass.

Effectiveness Of Material Separation;

• PET/PVC	Excellent
• PVC/PE	Good
• PET/PC	Fair
• PET/PS	Poor
• PET/PE	Poor

The system has good temperature range capability though <u>highest humidity</u> days deteriorates performance. Separation results obtained for different ratios of PET and PVC is ≈ equivalent; ranges tested 50:50 to 99:1

(PET:PVC). The presence of aluminum particles does not inhibit separation. Larger size particles require more energy for separation.

At the present time, test results indicate that in commercial use the electrostatic separation of plastic fragments would preferably involve tumbling the mixed plastic fragments to induce the desired electrostatic charges on the surfaces thereof and allowing these charged fragments to free fall, initially as a curtain, between oppositely charged electrodes disposed on opposite sides of and parallel to the curtain to cause separation of the fragments by migration with positively charged fragments being attracted toward the negative electrode and negatively charged fragments being attracted toward the positively charged electrode. The separated fragments would be collected in hoppers at the end of their free fall.

Such an apparatus is illustrated diagrammatically in Figure 4. With reference to Figure 4, a hopper 50 is arranged, by means of a chute 51, to supply a stream of plastic fragments to the inlet end 52 of a charging drum 53. The stream comprises a mixture of different plastic materials, the separation of which is desired. The different materials involved are capable of carrying electrostatic charges of opposite polarities on their surfaces. The particles are tumbled in the drum 53 to induce on their surfaces the desired electrostatic charge. To this end, the drum is rotated about its longitudinal axis 54 by a motor 55 and belt 56 drive. Rotation of the drum is facilitated by support of the drum on four support rollers 57 (two only being shown) located to support the drum for rotation about the axis 54. The rollers are

supported by a frame 58 which also supports the hopper 50 and chute 51.

Longitudinally extending vanes 59 are disposed on the inner periphery of the drum 53 to cause the fragments in the drum to tumble as the drum is rotated thereby to induce the electrostatic charge. The axis 54 of the rotation of the drum 53 is inclined downwardly, from the inlet end 52 to an outlet end 60, at an angle which, together with the quantity of fragments being supplied from the hopper and the rate of tumbling rotation of the fragments, will result in a desired residence time of each fragment in the drum chosen to achieve the desired electrostatic charge on the surface of the fragments as they pass through the drum from the inlet end to the outlet end.

The charged stream of fragments leaving the outlet end 60 of the drum 53 is fed onto the upper surface of a distributor plate 61 over which the fragments pass to a straight curtain forming edge 62. The slope and shape of the plate 61 is chosen to facilitate distribution of fragments passing thereover so that they form a substantially even curtain of fragments as they fall from the straight edge 62. The passage and distribution of the fragments over the plate 61 is facilitated by a vibrator 63 mounted on the frame 58 and connected to the plate 61 to vibrate that plate.

The edge 12 is disposed substantially evenly between the top edges of two parallel flat plate electrodes 64 and 65, with electrode 64 being connected to the positive terminal and electrode 65 being connected to the negative terminal of a high voltage generator 66 for generating positive and negative electrostatic fields. The edge 62 is parallel to the planes of the electrodes 64 and 65 and

the electrodes 64 and 65 extend downward on either side of the curtain free falling from the edge 62. As the charged fragments of the curtain free fall between the electrodes those with a positive charge are attracted toward and will migrate toward the negative electrode 65 while those with a negative charge will be attracted toward and will migrate toward the positive electrode 64 thereby separating the positive charged fragments from the negatively charged fragments.

Between the lower ends of electrodes 64 and 65 are disposed collection hoppers 67, 68 and 69 with the hopper 67 being disposed to receive substantially only negatively charged fragments, hopper 68 being disposed to receive substantially only positively charged fragments and hopper 69 being disposed between hoppers 67 and 68 to receive commingled fragments which have failed to separate. These commingled fragments may be recycled to hopper 50 for further separation treatment in the apparatus or otherwise disposed of. Separation efficiencies have been achieved which indicate that the hopper 69 may be unnecessary and thus not needed in commercial application. The location of the division between the hoppers 67, 68 and, if present, 69 is chosen in dependence upon the magnitude of the charge induced in the different fragments with the consequent difference in migration which will be achieved while under the influence of the electrostatic fields generated by the electrodes 64 and 65. The hoppers 67, 68 and 69 have respective outlet ducts 70, 71 and 72 through which the fragments collected in the hoppers may be extracted by, for example, suction or screw conveyor means extending into the hoppers through the ducts for onward passage to later stages of the recycling process or disposal of unwanted fragments.

It will be appreciated that the length of the free fall of the fragments is chosen to prevent them from migrating the entire distance to either of the electrodes thereby preventing the fragments from attaching themselves to either electrode while ensuring that they migrate a sufficient horizontal distance to fall into the desired hopper 67 or 68.

The curtain is shown by the arrows indicated as 73 with positively charged fragments migrating as generally indicated by arrows 74 and negatively charged fragments migrating as generally indicated by arrows 75. Commingled fragments which have not separated are indicated by arrow 76.

It will be appreciated that many different arrangements of the electrostatic separation structure are possible without departing from the inventive concept.

Among the many configurations which will be apparent to appropriately skilled men are those illustrated in Figures 5, 6, 7 and 8. In Figure 5 a single electrode corresponding to positive electrode 64 is used. This electrode is cylindrical with concentric hoppers 67 and 68 disposed at the bottom and inside of thereof. A stream of charged fragments are allowed to free fall along the central axis of the cylindrical electrode. The negatively charged fragments (e.g. PVC) in that stream are attracted toward the electrode 64 whereby they migrate radially outwardly as they fall to be collected in the outer annular hopper 67. Fragments (e.g. PET) which do not carry a charge or which are positively charged free fall along the axis of the electrode as a result of not being attracted by the electrostatic field generated by the electrode or, in the case of the positively charged fragments, as a result of the repulsion by that

electromagnetic field, into the central hopper 68. A variation of this design involves an arrangement in which a cylindrical outer electrode surrounds an inner electrode which is concentric with the outer cylindrical electrode and of opposite polarity thereto. The hoppers would be appropriately positioned to receive their respective supply of positively and negatively charged fragments in this arrangement. Such a design in essence amounts to a modification of the arrangement of Figure 4 in which the electrodes are wrapped around form concentric cylindrical electrodes. In such an arrangement the curtain would be a circular curtain created, for example, by a right conical distributor plate positioned to receive a stream of charged fragments centrally on its pointed upper end and to create the curtain at its circular lower periphery. It will be appreciated that while certain electrodes are described herein as positive and other electrodes are described herein as negative these could be reversed in any configuration as would be appropriate with the polarity of electrostatic charges of the fragments to be separated.

In the arrangement of Figure 6, a single planar electrode 64 is energized to create a positive electrostatic field which attracts negatively charged (e.g. PVC) fragments of a curtain 73 in order that they migrate horizontally to be collected in hopper 67 while positively charged fragments or fragments carrying no charge fall into hopper 64 with some repulsion resulting in migration of the positively charged fragments away from the electrode 64. A variation of Figure 6 is shown in Figure 7 in which two positively charged electrodes attract negatively charged fragments from a curtain or stream for collection in hopper 67 while positively

charged fragments or fragments having no charge fall into hopper 68.

The present invention is also applicable to the separation of fragments all of which can carry a charge of the same polarity. The requirement in such a process is that the fragments to be separated must carry magnitudes of charge sufficiently different for attraction or repulsion by an electrostatic field to cause different degrees of migration normal to the free fall direction thereby to facilitate the desired separation. Figure 8 illustrates such an arrangement in which a positively charged electrode 64 generates a positive electrostatic field which causes separation of a curtain 73 of fragments all of which are negatively charged with fragments of different materials being charged to different negative magnitudes of charge respectively. As a result all of the fragments will be attracted toward the electrode 64 with those having the greater negative charge migrating a greater distance toward that electrode whereby the fragments having the greater negative charge fall into hopper 67 while those having the lesser negative charge fall into hopper 68. As will be appreciated, differential repulsion or a combination of attraction and repulsion could be used for this purpose.

The present invention is not restricted to electrodes which are vertically cylindrical or flat. For example, electrodes could be curved or sloped outwardly relative to the curtain stream of charged fragments to maximize attraction and/or repulsion of the charged fragments while avoiding the possible migration of those fragments onto the electrodes concerned as they free fall (see Figure 9).

Additionally, with appropriate control of electrostatic charges and fields and electrode facing

material, migration of fragments into contact with the electrode(s) might be tolerated or encouraged with contacting fragments falling or passing over the contact electrode face for collection.

Figure 10 illustrates the charged distribution in nanocoulombs (nC) achieved with a mixture of 90% PET and 10% PVC fragments not exceeding 1/4 inch maximum dimension in which the fragments were hand tumbled for 20 seconds to achieve an electrostatic charge on the surfaces thereof. This figure illustrates that 100% separation of the PET and PVC can be achieved if the division between hopper 67 and 68 is placed at a location where fragments having a charge of 0.1 nC will land after their free fall. This experiment showed that the main charge achieved for PET was 0.026 nC with a standard deviation of 0.03 nC while the mean value for PVC is -0.232 nC with a standard deviation of 0.064 nC. The result of this test considering the deviation in charges of PET and PVC fragments is that by setting the collection bins in which the division of the bins is at the falling point of -0.04 nC will remove all but 100 parts per million (ppm) of PVC from the mixture of PVC and PET fragments. With this being achieved the loss of only 1.4% of the PET. Further testing indicated that the charge to mass ratio (q/m) of PVC was significantly higher than that of PET with the result that separation would involve significantly greater migration of PVC fragments compared to that of PET. This is believed due to the anisotropic shape of the fragment in which one dimension (the wall thickness) of the bottle is independent of the size of the chips with the result that bigger chips have significantly greater surface area than smaller chips without the attendant increase in mass which would result if the fragments were spherical. As a

result of this test, it is believed that the use of larger fragments in the separation process is superior to that of the use of smaller fragments as larger fragments are less likely to be blow around and are less effected by air drag.

Figure 11 illustrates the distribution of charge for large particles (all between 1/8 to 1/4 inch maximum dimension) with the few fragments in the gap between the PVC and PET being of PVC. With this distribution the desired separation of PET and PVC can be achieved. Further tests illustrate that separation is excellent with relative humidities are kept to no more than 40%. Significant degredation and performance occurs with relative humidities exceeding 70%. Satisfactory performance is expected to be achieved with relative humidities of 50% or less. Further, the desired purity of achieving less than 100 ppm of PVC in the PET output can be achieved with PET/PVC mixes which contain up to 10% of PVC. The choice of material from which the drum is manufactured or at least the portion of the drum coming into contact with the fragments conveyed and tumbled therein is of importance in determining the amount of charge the fragments will achieve. In testing, the best performance came from steel exterior with a vinyl or lacquer lining with the vanes constructed of steel. However, satisfactory results have been achieved with a drum made of one of the materials to be separated e.g. PVC or PET.

As a result of testing it appears at this time that the best result will be achieved with a steel drum having a vinyl lining with steel vanes used to tumble a mixture of PVC and PET, having up to 10% PVC, comprising fragments of approximately 1/4 inch maximum dimension. The mixture

of PET and PVC fragments may have mixed therein some oversized PVC fragments to improve the charge distribution between the PVC and the PET. The relative humidity should be at or below 50% and preferably at or below about 40%. The separation design illustrated in Figure 4 can readily be sized to process 2,000 pounds or more of PET/PVC fragments per hour.

Satisfactory results are achieved where separation takes place with fragments at an elevated temperature up to about 250°F with the desired separated impurity level of 100 ppm of PVC in the PET being achieved with the separation point being set at -0.2 nC resulting in a loss of little more than 1% of PET in the separation process when the drum is constructed of lacquer coated steel. By salting the mixture to be separated with oversized PVC chips, the PET average charge is increased to a more positive value with little obvious effect from the PVC charge. The result of this is that the 100 ppm impurity level of the separated PET can be achieved at a separation charge of -0.25 nC with the loss of PET of only slightly over 0.1%. These figures apply to the case in which separation occurs at an elevated temperature as referred to above. However, an improvement in operation is expected at all separation temperatures.

To achieve a separation throughput of 2,000 pounds per hour with a preferred residence time of 5 minutes of the fragments in the drum 53 the drums volume is typically 0.17 cubic meters with the fragments occupying approximately 3/4 of the drum.

We claim:

1. A method of separating mixed fragments of different materials, at least one said material being capable of carrying an electrostatic charge by which it can be caused to migrate under the influence of an electrostatic field sufficiently to separate it from at least one other said material, comprising the steps of:

a) inducing said electrostatic charge on said at least one said material;

b) exposing the materials to an electrostatic field capable of causing migration of said at least one material relative to at least said one other said material;

c) allowing said at least one material to migrate under the influence of said field thereby to separate said materials; and

d) collecting the separated material fragments;

wherein the induced electrostatic charge on said at least one material is sufficient to facilitate said migration while being insufficient for any oppositely charged fragments of said materials to be attracted to each other sufficiently to prevent said migration.

2. A method according to claim 1, wherein the materials are plastic, said at least one material is capable of carrying an electrostatic charge different from that the other(s) of said materials are capable of carrying and the different electrostatic charges are induced on said materials.

3. A method according to claim 2 in which the electrostatic charges induced in the fragments are of different magnitudes and the charged fragments are exposed to an electrostatic field while in free fall with the

difference in migration resulting from said different magnitudes of charge providing the desired separation of fragments.

4. A method according to claim 2 wherein the materials to be separated are capable of carrying electrostatic charges of opposite polarities and the opposite electrostatic charges are induced in said materials.

5. A method according to claim 4 wherein the oppositely charged materials are exposed to electrostatic fields of opposite polarities and are allowed to migrate toward their respectively oppositely charged fields thereby to separate said materials;

the induced opposite electrostatic charges on said materials being sufficient to facilitate said migration while being insufficient for the fragments of said materials to be attracted to each other sufficiently to prevent said migration.

6. A method according to claim 4 wherein the fragments are allowed to migrate in accordance with their change under the influence of said electrostatic field as they free fall through that field.

7. A method according to claim 1 wherein the electrostatic charge is induced by tumbling the mixed fragments together for a sufficient time to achieve a desired said charge.

8. A method according to claim 2 wherein the different electrostatic charges are induced by tumbling the mixed fragments together for a sufficient time to achieve desired said charges.

9. A method according to claim 4 wherein the electrostatic charges of opposite polarities are induced

by tumbling the mixed fragments together for a sufficient time to achieve desired said charges.

10. A method according to claim 1 in which the charged mixture of fragments are manipulated into a curtain of fragments and the curtain of fragments is exposed to the electrostatic field while in free fall.

11. A method according to claim 4 in which the different plastic materials are PET and PVC and the electrostatic fields of opposite polarity are vertically extending fields between which the charged fragments are allowed to fall to allow the desired separation.

12. A method of separating mixed fragments of different plastic materials, the materials to be separated being capable of carrying electrostatic charges of opposite polarities, comprising the steps of:

a) inducing said electrostatic charges in said materials;

b) exposing the charged materials to electrostatic fields of opposite polarities;

c) allowing said charged materials to migrate toward their respectively oppositely charged fields thereby to separate said materials; and

d) collecting the separated material fragments;

wherein the induced electrostatic charges in said materials are sufficient to facilitate said migration while being insufficient for the fragments of said materials to be attracted to each other sufficiently to prevent said migration.

13. A method according to claim 12 further comprising the step of inducing sufficient electrostatic charge in said materials to cause them to be attracted toward a respectively oppositely charged field without

inducing interparticular attraction between particles of unlike charge.

14. A method according to claim 13 further comprising the step of inducing said charge for a period of about 30 to 60 seconds.

15. A method according to claim 12 further comprising the step of recycling material fragments which have failed to migrate toward their respective oppositely charged fields.

16. An apparatus for carrying out the method of claim 1 comprising:

a) means for inducing said electrostatic charge on the fragments of said at least one material;

b) means for producing an electrostatic field capable of causing migration of said charged fragments relative to at least one other said material;

c) means for exposing said mixed fragments to said field; and

d) means for collecting the separated material fragments.

17. An apparatus for carrying out the method of claim 2 comprising:

a) means for inducing said electrostatic charges on the fragments;

b) means for producing an electrostatic field capable of causing differential migration of the differently charged fragments to separate them in accordance with the different charges;

c) means for exposing said mixed fragments to said field; and

d) means for collecting the separated material fragments.

18. An apparatus for carrying out the method of claim 4 comprising:

a) means for inducing said electrostatic charges of opposite polarities in said mixed material fragments;

b) means for producing a said electrostatic field;

c) means for exposing said charged fragments to said field; and

d) means for collecting the separated material fragments.

19. An apparatus according to claim 18 in which the means for producing said electrostatic charges is a means for tumbling the mixed fragments to be separated.

20. An apparatus according to claim 19 wherein the means for tumbling is a drum defining a longitudinal axis and mounted for rotation about that axis, said axis being inclined downwardly from an inlet end of the drum, positioned to receive the mixed fragments to be separated, to an outlet end of the drum positioned to discharge the charged fragments from the drum, said drum including vanes mounted therein to cause tumbling of the mixed fragment as the drum rotates, the fragments being conveyed from the inlet end to the outlet end during tumbling.

21. An apparatus according to claim 20 wherein the drum is constructed of steel coated on its interior with one of vinyl and lacquer.

22. An apparatus according to claim 20 wherein the vanes are attached to the interior periphery of the drum and extend longitudinally of the drum.

23. An apparatus according to claim 20, wherein the outlet end of the drum is positioned so that charged fragments discharged therefrom fall onto a distribution

means which evenly distributes the exiting fragments so that they fall therefrom as a curtain of charged mixed fragments.

24. An apparatus according to claim 23, wherein said distribution means is a plate positioned to cause said curtain of mixed charged fragments tc fall centrally between vertically extending electrode, arranged to generate electrostatic fields of opposite polarities, to allow said separation during free fall of the fragments between the electrodes.

25. An apparatus according to claim 24 in which the charged mixed fragments are exposed to said electrostatic fields in a free fall space to allow said separation.

26. An apparatus according to claim 25 in which collection hoppers are provided at the lower end of the free fall space positioned to collect the separated fragments.

27. An apparatus according to claim 24 in which the distribution plate has an upper surface over which the charged mixed fragments are distributed and conveyed to a curtain forming straight edge of the plate, means being provided for vibrating the plate to achieve the desired distribution and conveyance.

28. An apparatus for carrying out the method of claim 12 comprising:

a) means for inducing said electrostatic charges in said mixed material fragments;

b) means for producing separate electrostatic fields of opposite polarities;

c) means for exposing said charged fragments to said fields;

d) means facilitating migration of said charged fragments toward said respectively opposite polarity fields; and

e) collecting the separated material fragments.

29. An apparatus according to claim 28 wherein the charged fragments are exposed to said electrostatic fields of opposite polarities while being conveyed along an inclined vibrating sheet.

30. An apparatus according to claim 29 wherein the inclined vibrating sheet is made from an insulating material.

31. An apparatus according to claim 30 wherein the inclined vibrating sheet is made from a plastic material which is the same as one of the materials to be separated.

32. An apparatus according to claim 29 wherein the migration of the charged plastic fragments towards respectively oppositely charged electrostatic fields is facilitated by means of path diverters positioned along the top of the inclined sheet.

33. An apparatus according to claim 2 wherein the charged fragments are exposed to said electrostatic fields of opposite polarities by means of allowing the charged fragments to free fall between two vertically standing and oppositely charged conductive plates.

34. An apparatus according to claim 29 wherein the means for producing separate electrostatic fields is capable of supplying a range of about 1,000 to 10,000 volts.

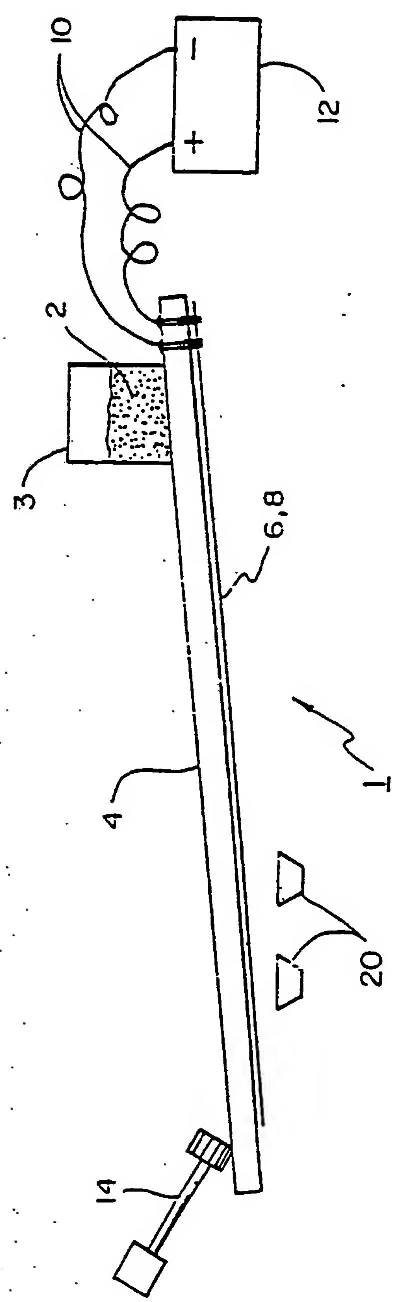

FIG. 1

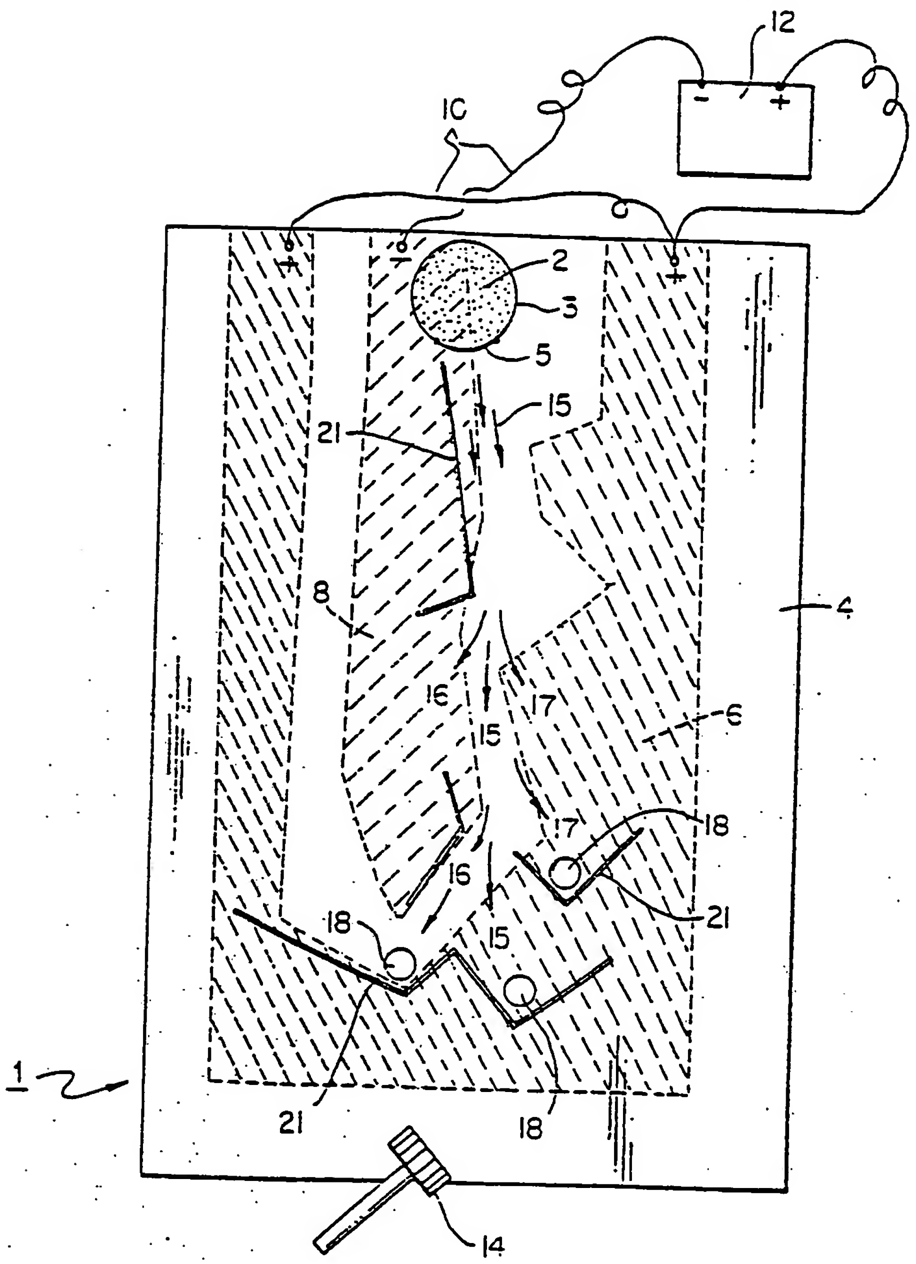

FIG. 2

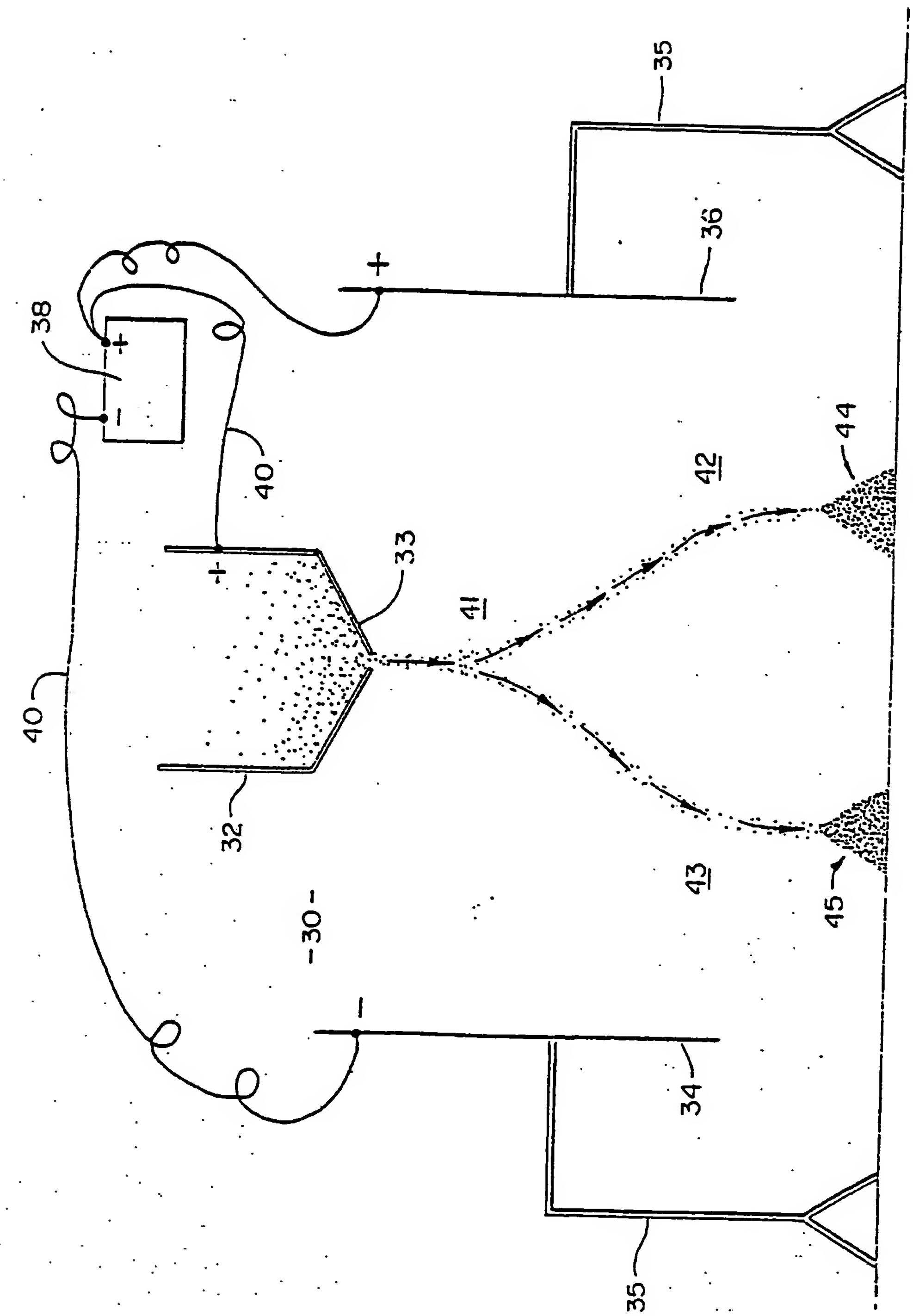

FIG.3

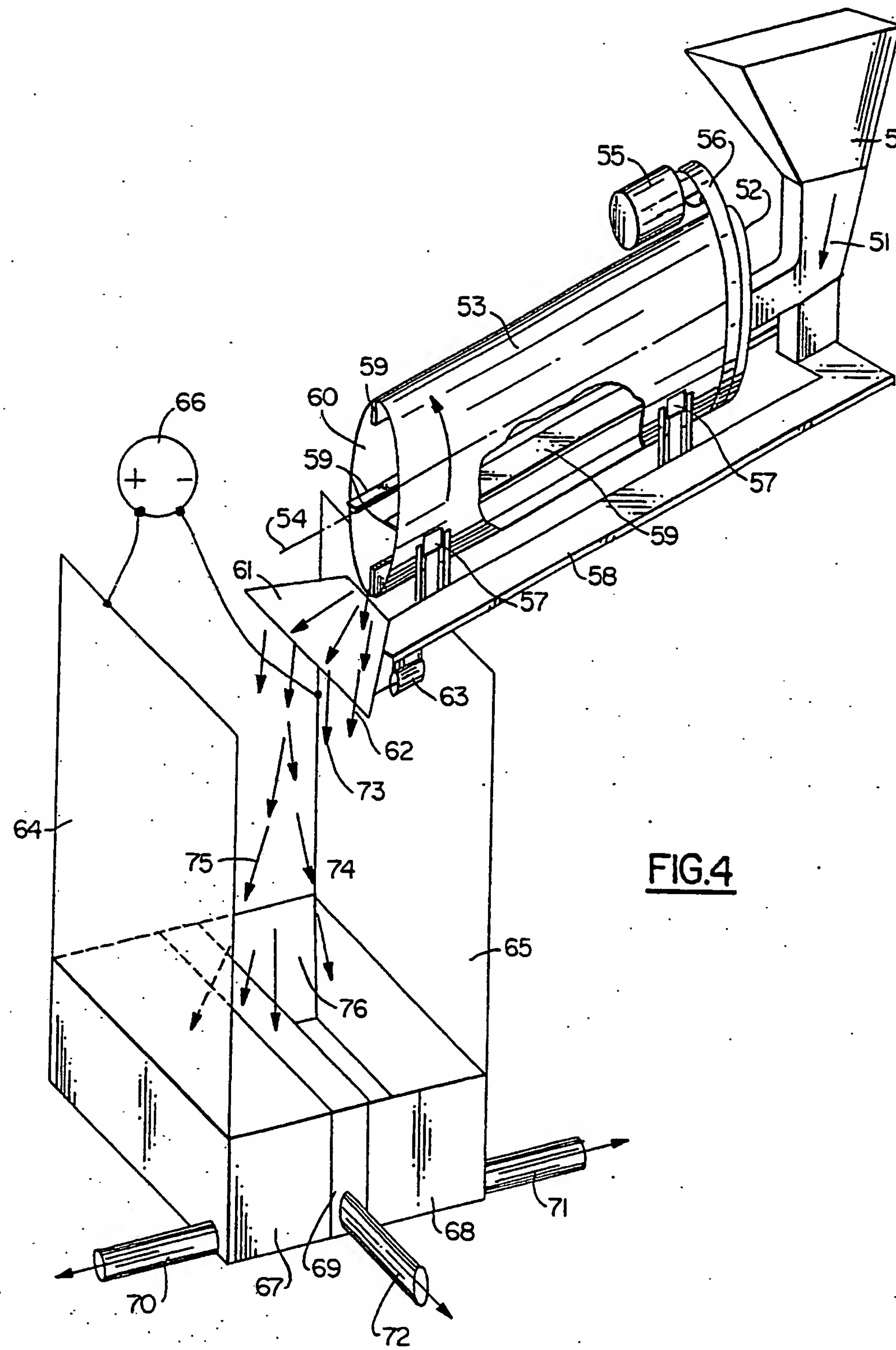
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FIG.4

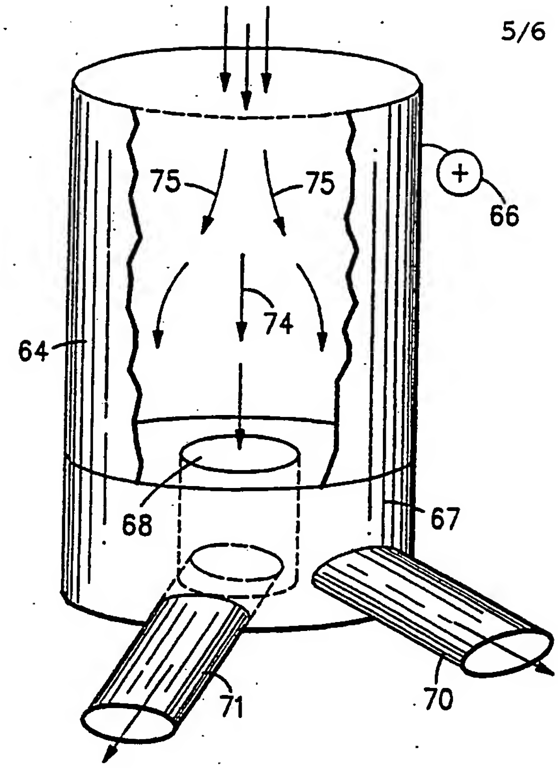


FIG.5

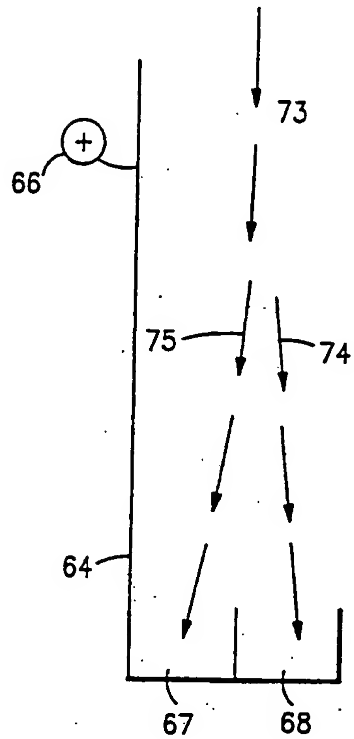


FIG.6

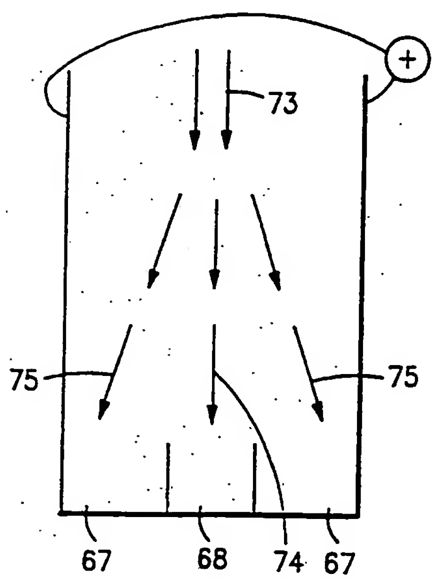


FIG.7

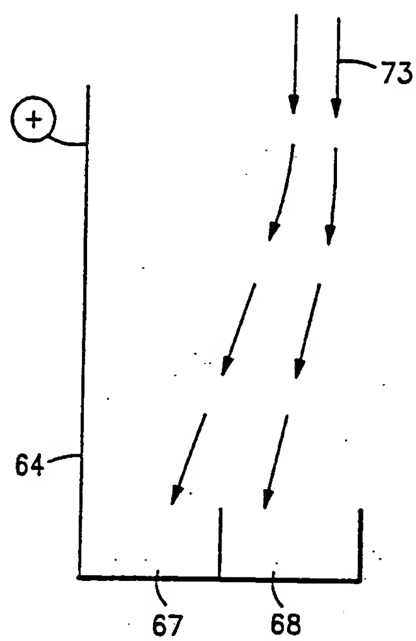


FIG.8

FIG.9

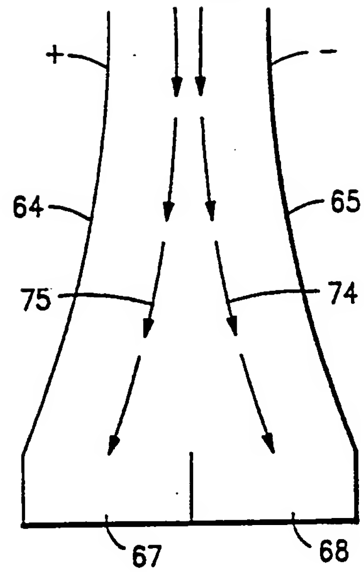


FIG.10

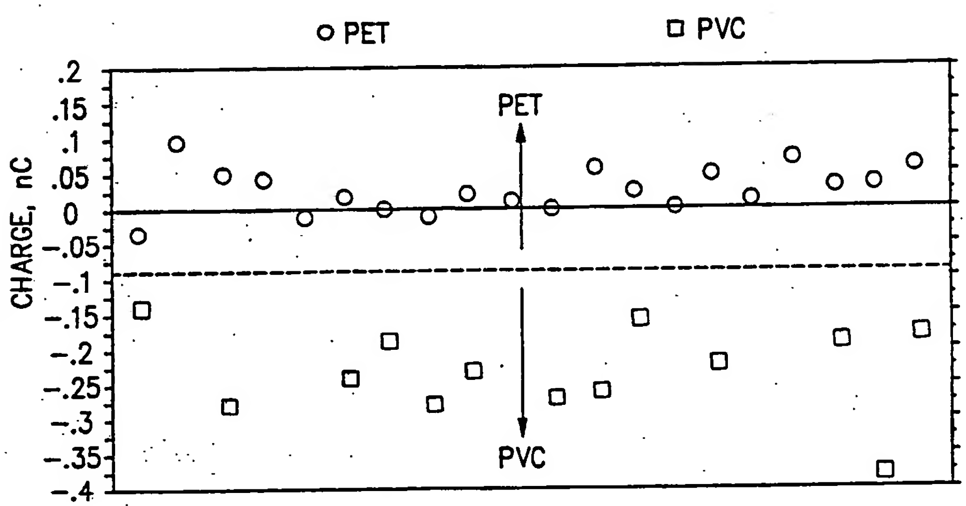
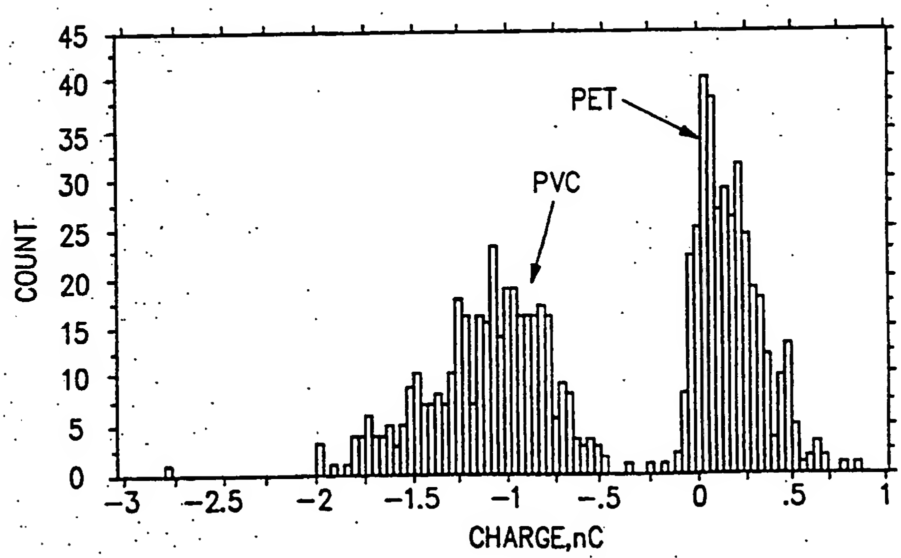


FIG.11



INTERNATIONAL SEARCH REPORT

International Application No. PCT/US92/00184

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC(5): B03C 7/02; B03C 7/12
US CL : 209/127.1,127.4,129

II. FIELDS SEARCHED

Minimum Documentation Searched

Classification System	Classification Symbols
U.S.	209/2,127.1,127.2,127.3,127.4,128,128

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched

III. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
X	US, A, 3,143,492 (BULLOCK) 04 AUGUST 1964 See col. 3, line 54-col. 4, line 30; fig. 3,9,10 and 11.	1,2,3,7,8,16, 17
A	US, A, 4,895,642 (FREI) 23 JANUARY 1990	
A	US,A , 4,570,861 (ZENTGRAF ET AL.) 18 FEBRUARY 1986	
A	US, A, 4,092,241 (MACKENZIE ET AL.) 30 MAY 1978	
A	US, A, 3,309,569 (HEYL ET AL.) 14 MARCH 1967	
A	US, A, 3,059,772 (LEBARON) 23 OCTOBER 1962	
A	DT, A, 3,213,399 (PATSCH) 20 OCTOBER 1983	
A	IT, A, 533,907 (TOTH) 04 OCTOBER 1955	

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- "A" document defining the general state of the art which is not considered to be of particular relevance
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- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- "&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
21 April 1992	20 MAY 1992
International Searching Authority	**Signature of Authorized Officer**
ISA/US	For Ngoc-Ho Nguyen DONALD T. HAJEC